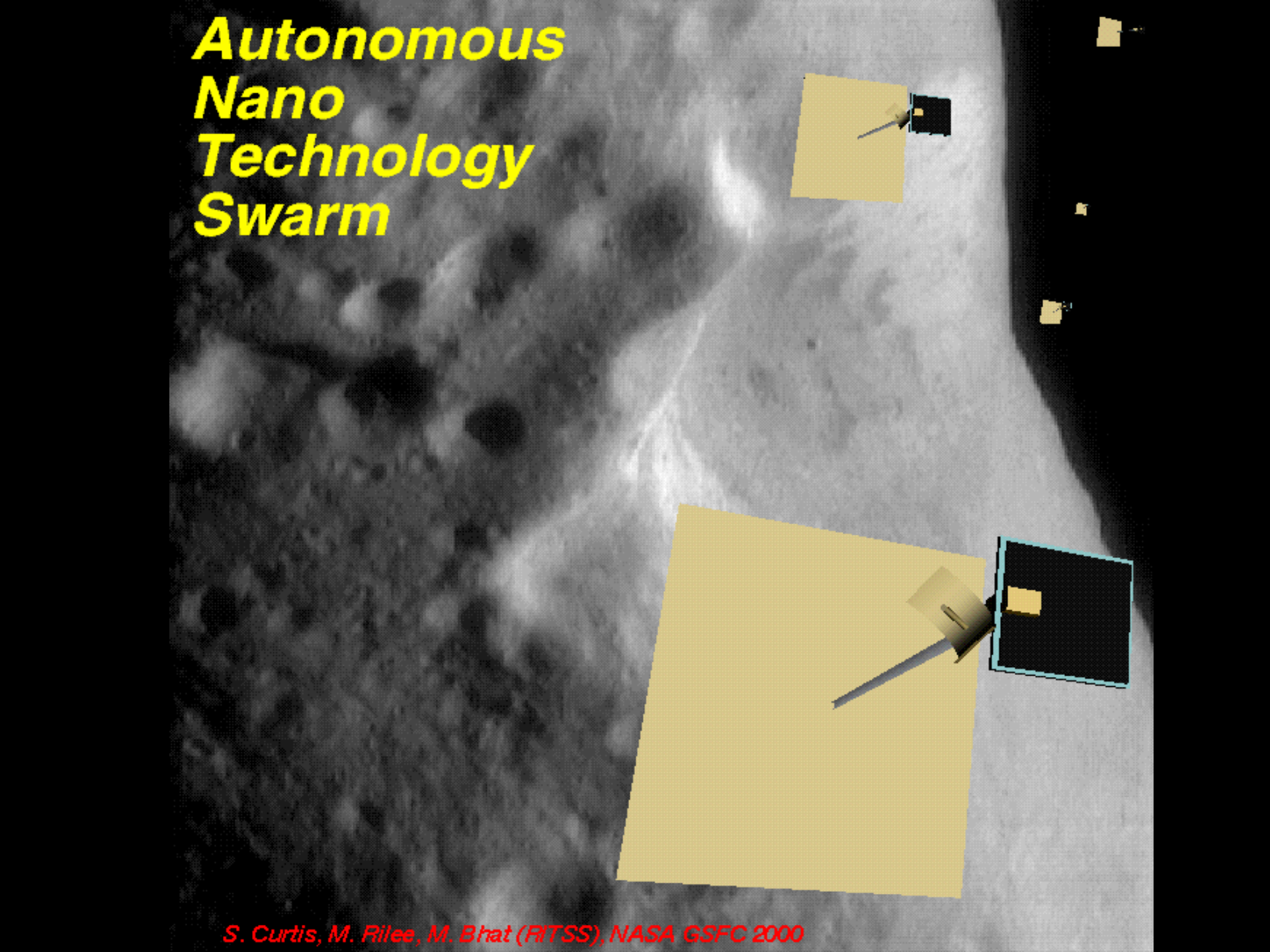
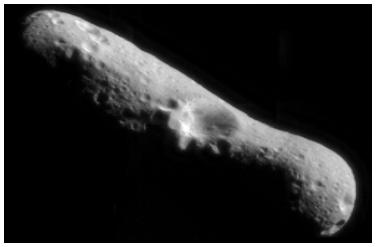

Autonomous
Nano
Technology
Swarm
S. Curtis, M. Rilee, M. Bhat (RITSS), NASA GSFC 2000

ANTS (Autonomous Nano Technology Swarm): An Artificial Intelligence Approach To Asteroid Belt Resource Exploration



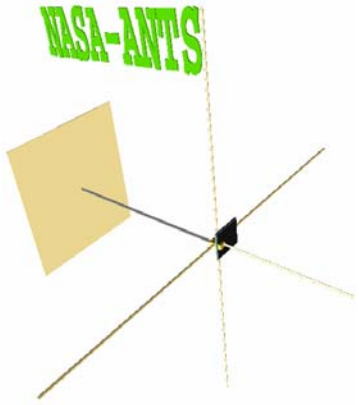
Steven A. Curtis

NASA Goddard Space Flight Center (GSFC)

Greenbelt, Maryland

J. Mica, and J. Nuth, G. Marr /GSFC

M. Rilee and M. Bhat /Raytheon ITSS



Presented at the

51st International Astronautical Congress

2-6 October 2000, Paper: IAF-00-Q.5.08

GSFC

Raytheon

THE NEXT FRONTIER

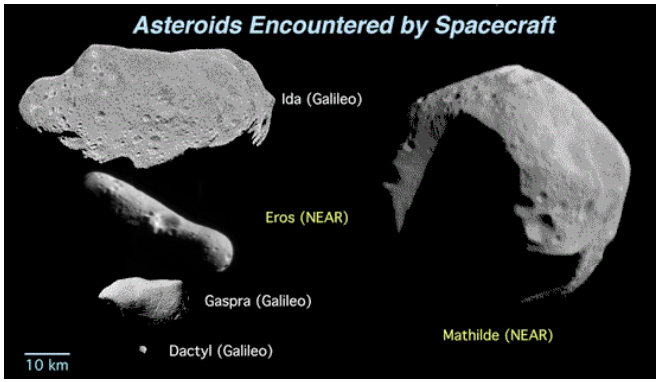
The Asteroid Belt is the next unexplored frontier after the exploration of Pluto and Mercury.

Study of the asteroid belt requires:

- **Science missions for insight into solar system origin and evolution,**
- **Exploration, survey, and prospecting for potential resources, and**
- **Further technology for autonomous and distributed systems.**

MISSION GOALS

- Scientifically categorize all asteroids > 1 km in diameter.
- Perform initial prospecting for potential resources.



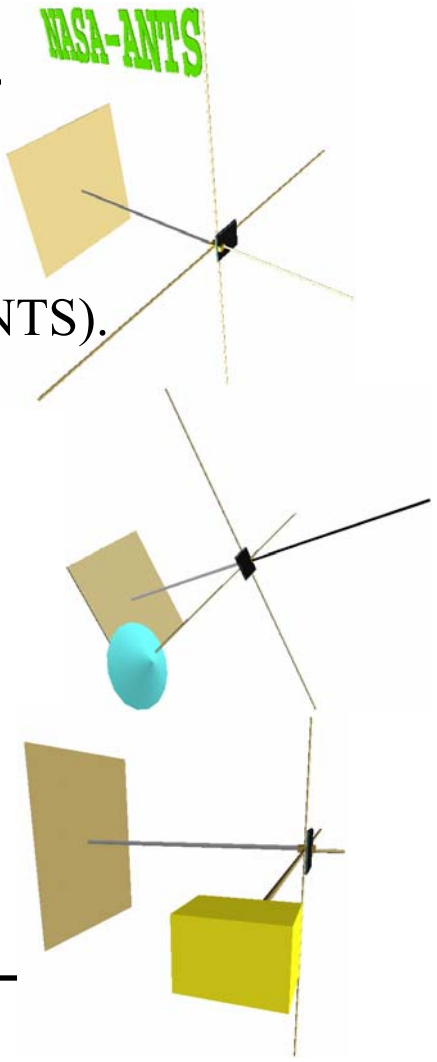
CHALLENGES

- Large number of Asteroids.
- Wide variety of instruments.
- Far from the Sun.
- Far from the Earth.
- Comparatively large ΔV requirement.

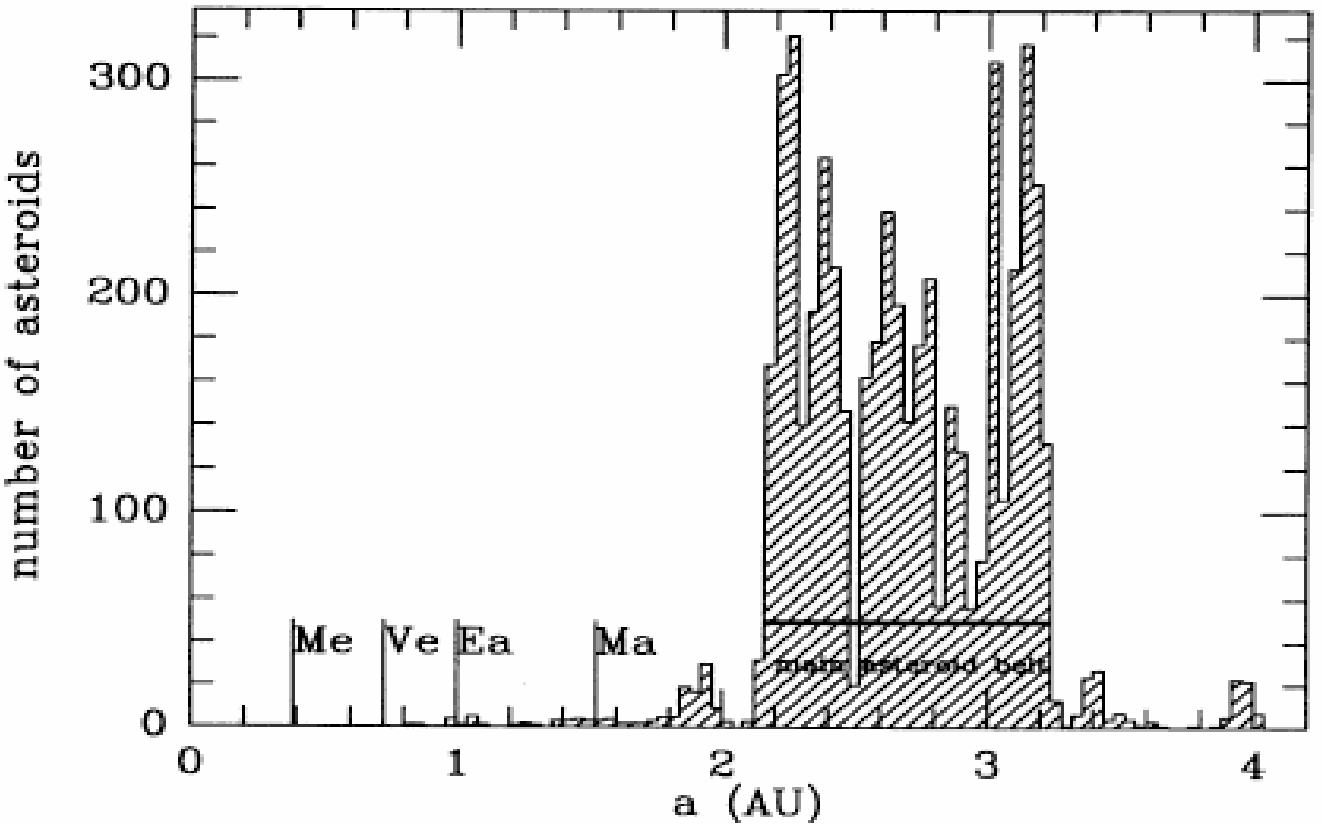
SOLUTION

AUTONOMOUS Nano Technology Swarms (ANTS).

- An insect colony analog.
- Large number of spacecraft.
- Very specialized spacecraft.
- Solar sails for ΔV.
- Very small spacecraft, picospacecraft.
- Highly autonomous operation.

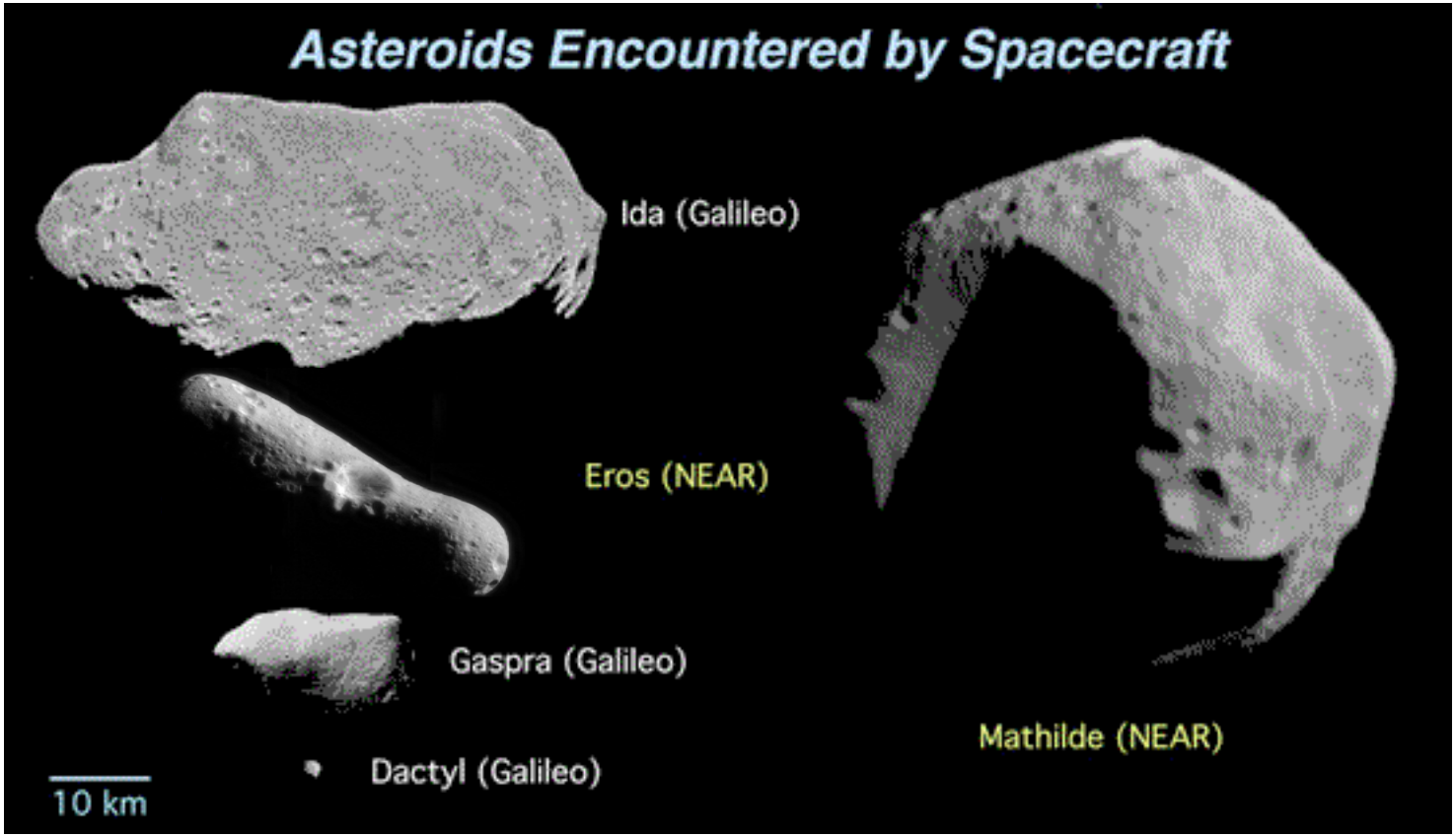


ASTEROID BELTS



S. Mikkola & K. Innanen (MNRAS, 1995)

ASTEROIDS

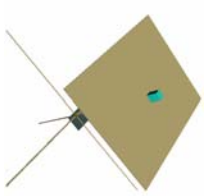

Asteroids Encountered by Spacecraft
Ida (Galileo)
Eros (NEAR)
Gaspra (Galileo)
Mathilde (NEAR)
Dactyl (Galileo)
10 km

SPACECRAFT

An ANT picospacecraft

- Present nanospacecraft extended to picospacecraft regime.
- An explorer complete with subsystems to carry out the mission.
- On-board computation, artificial intelligence, heuristics systems for control at all levels.
- Solar sail propulsion systems.
- Inter-spacecraft communications :
  - Low bandwidth (LBW) for distance, swarm cohesion, collective behavior.
  - High bandwidth (HBW) for data transfer.
- **Types**
  - Ruler/Messenger
  - Worker

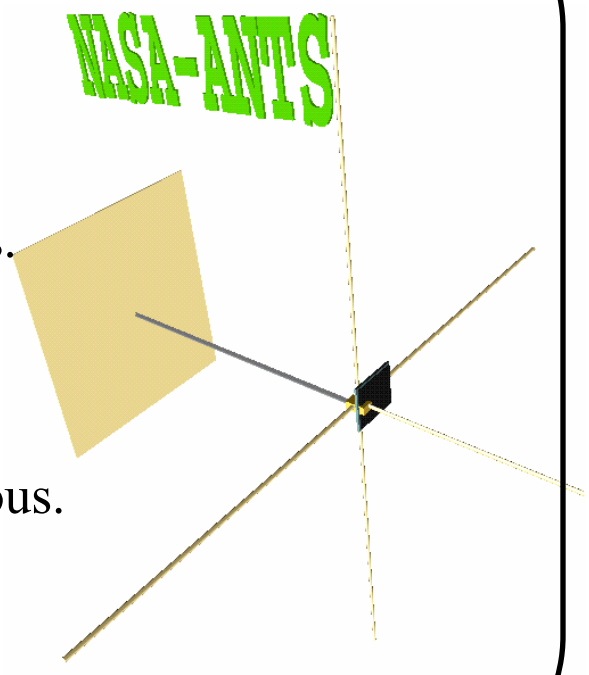
Ruler/Messenger



Worker

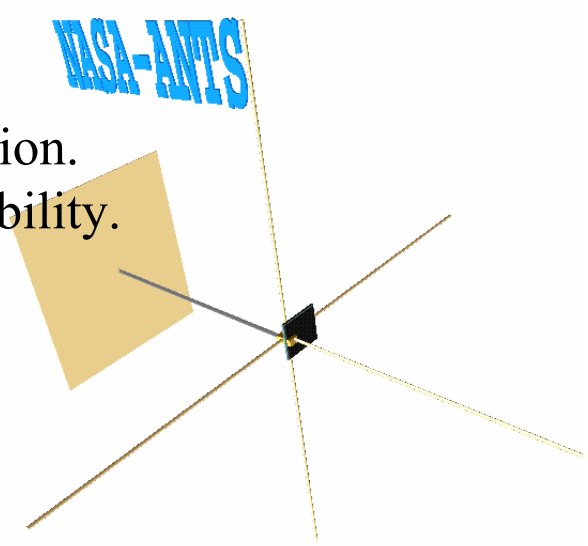
RULER ANT

- Swarm heuristics operations planner.
- Assign workers, maintain swarm statistics.
- Manage overall mission objectives.
- Distributed intelligence operations.
- Resolve local/mission conflicts.
- Navigation, collision avoidance, rendezvous.
- Communications and relay.



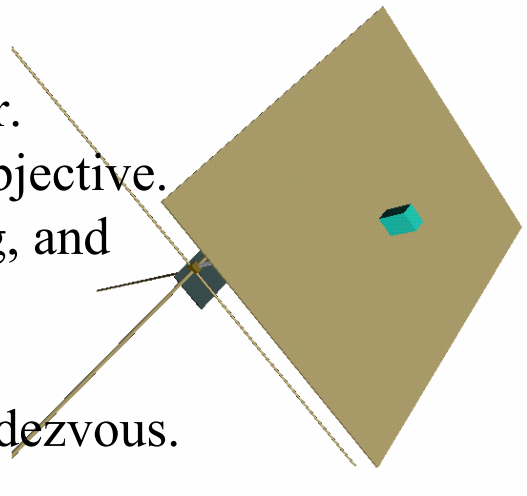
MESSENGER ANT

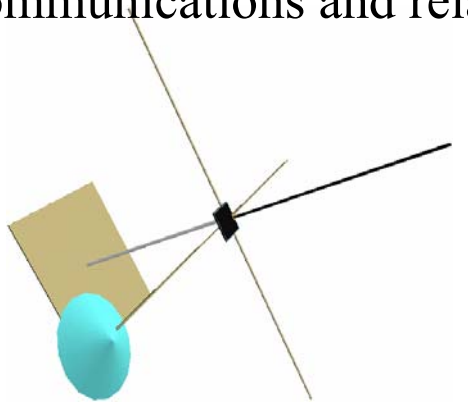
- Similar to Ruler.
- Higher ΔV.
- More communication.
- Limited science instrumentation.
- Lesser or dormant CPU capability.

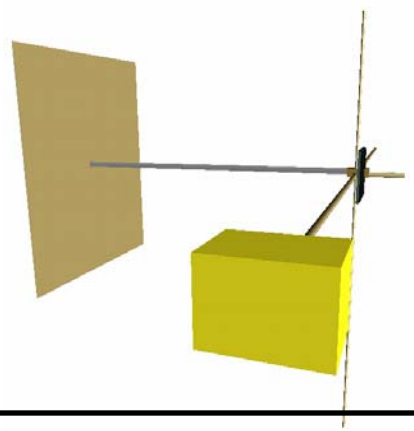


WORKER ANT

- Worker heuristics operations planner.
- Customized for particular mission objective.
- Data acquisition, processing, sharing, and Messenger delivery.
- Resolves conflicts.
- Navigation, collision avoidance, rendezvous.
- Communications and relay.







MINIATURIZED INSTRUMENTS

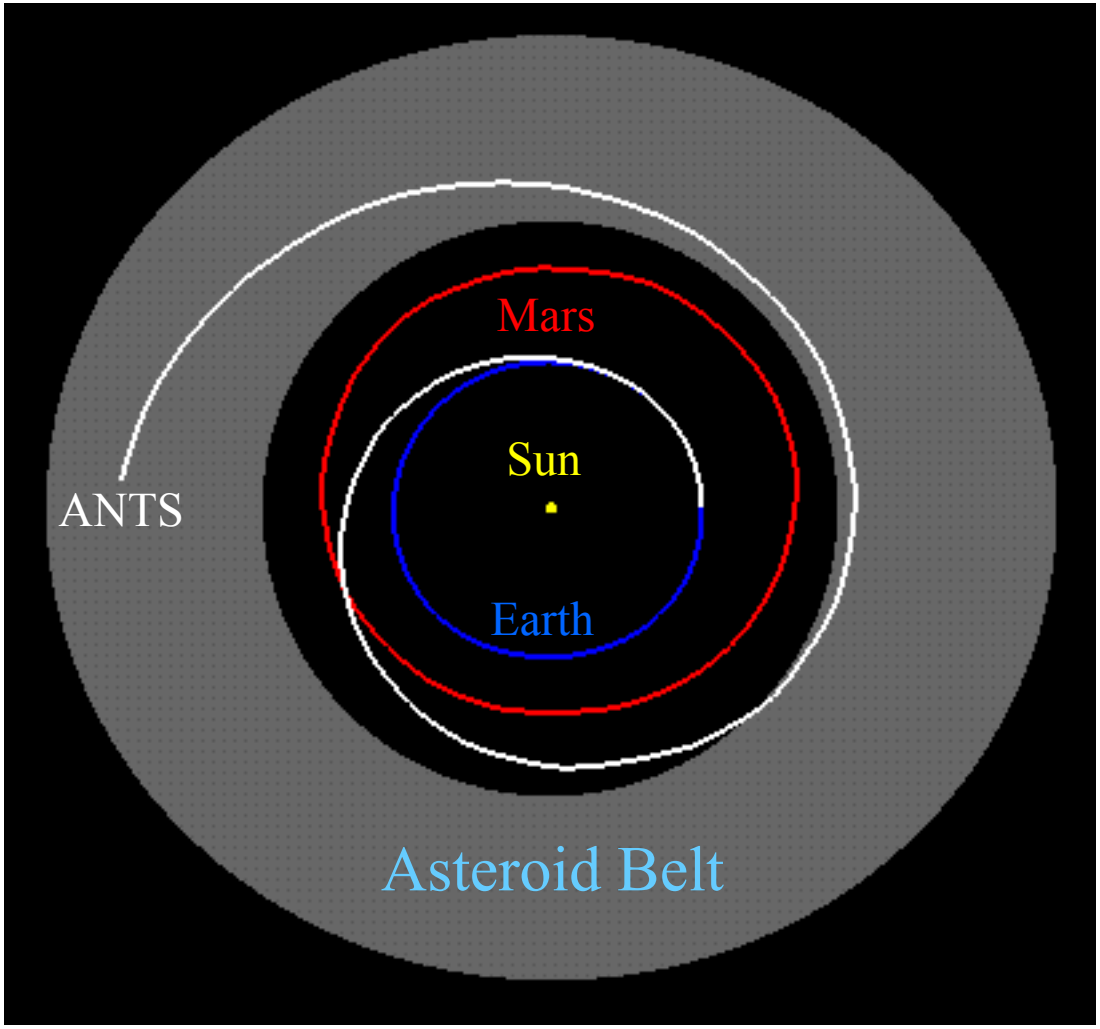
- Examine limits.
- Preserve functionality.
- General survey type initial mission.
- Requirement to catalog mass, density, morphology, chemical composition.

Basic Instruments:

Magnetometers, Radiosounders, Radar, Lidar, X-ray Fluorescence Spectrometers, Gamma-ray Spectrometers, Visible-near-IR spectrometers, Thermal-IR Spectrometers, Mass Spectrometers, Monochromatic imaging cameras and Accelerometers.

ANTS TRANSFER ORBIT

- Solar sail size: 100 m^2
- S/C Mass: 1 kg
- Flat plate normal from sun line: 30^o
- Transfer to: 2.8 AU
- Transfer time: 3.5 yr.
- da/dt~100 Mm/12 hrs.



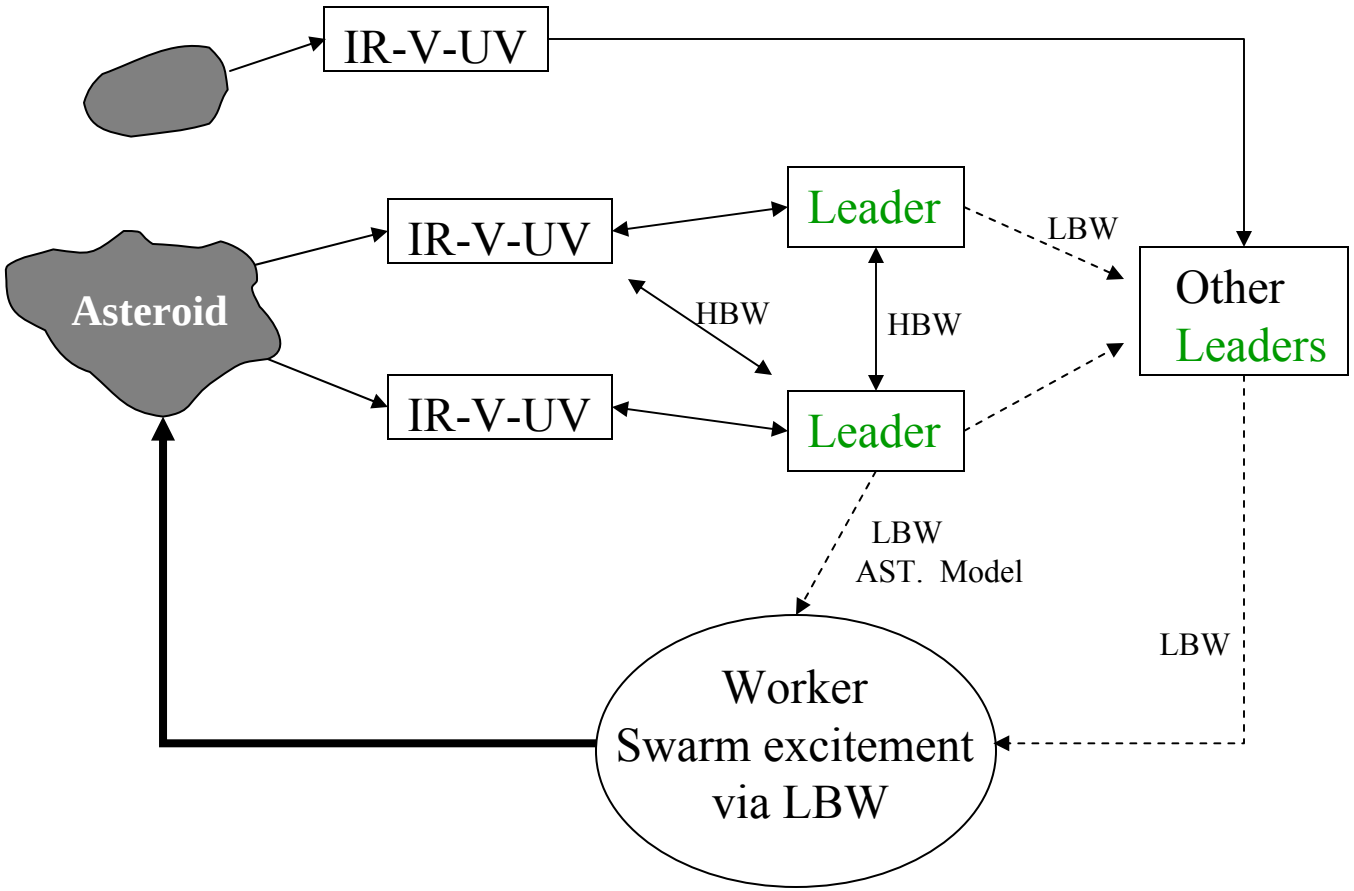
ENCOUNTER WITH AN ASTEROID

Ant Model Features:

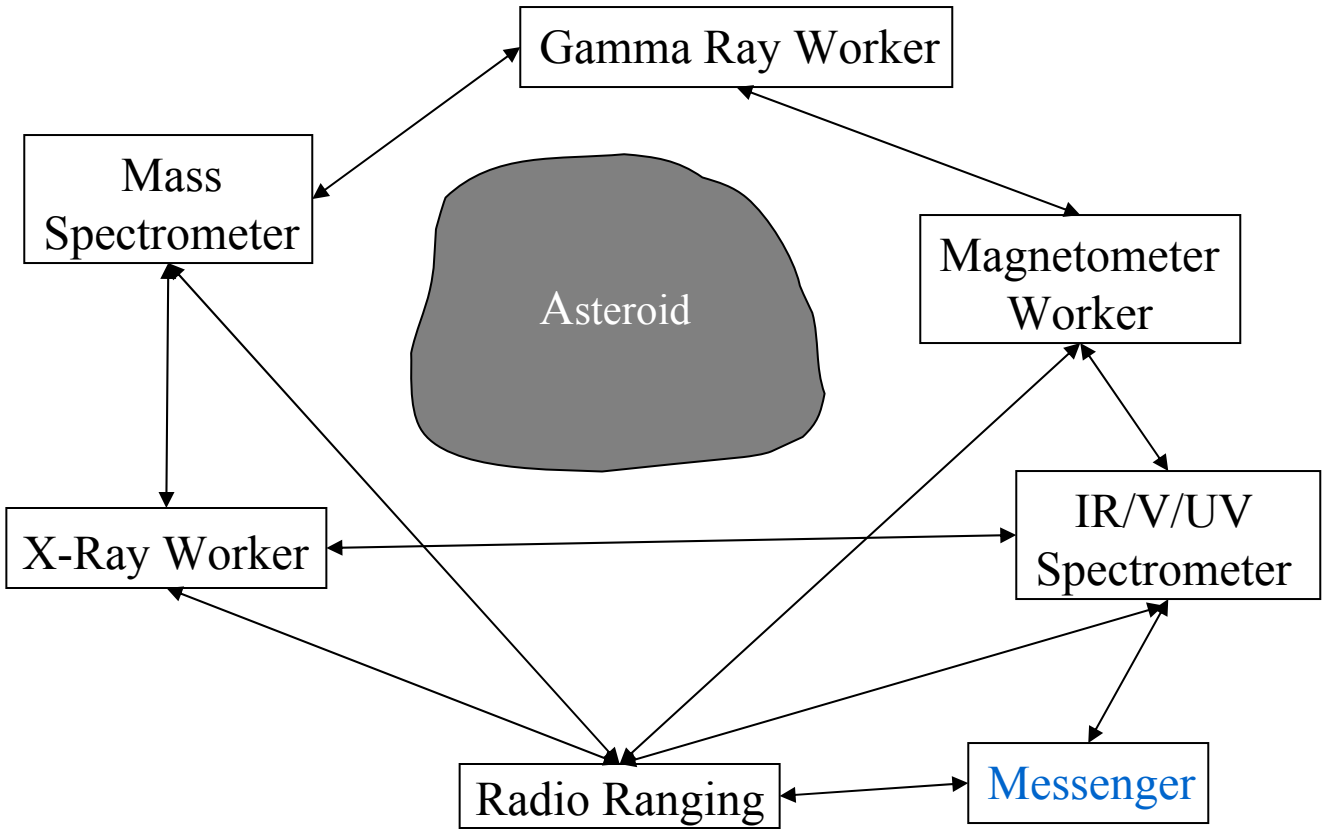
- Neural like signaling using radio beacon.
- LBW/HBW capability.
- LBW for colony-global behavior.
- HBW for specific data transfers.
- Customized for particular mission oriented data.
  - Workers: autonomous, sensing capability.
  - Messengers: high acceleration, dart from ANT to ANT, relieve workers of data.
  - Rulers : excite various behaviors in ANTS.

LBW: Low bandwidth; HBW: High bandwidth

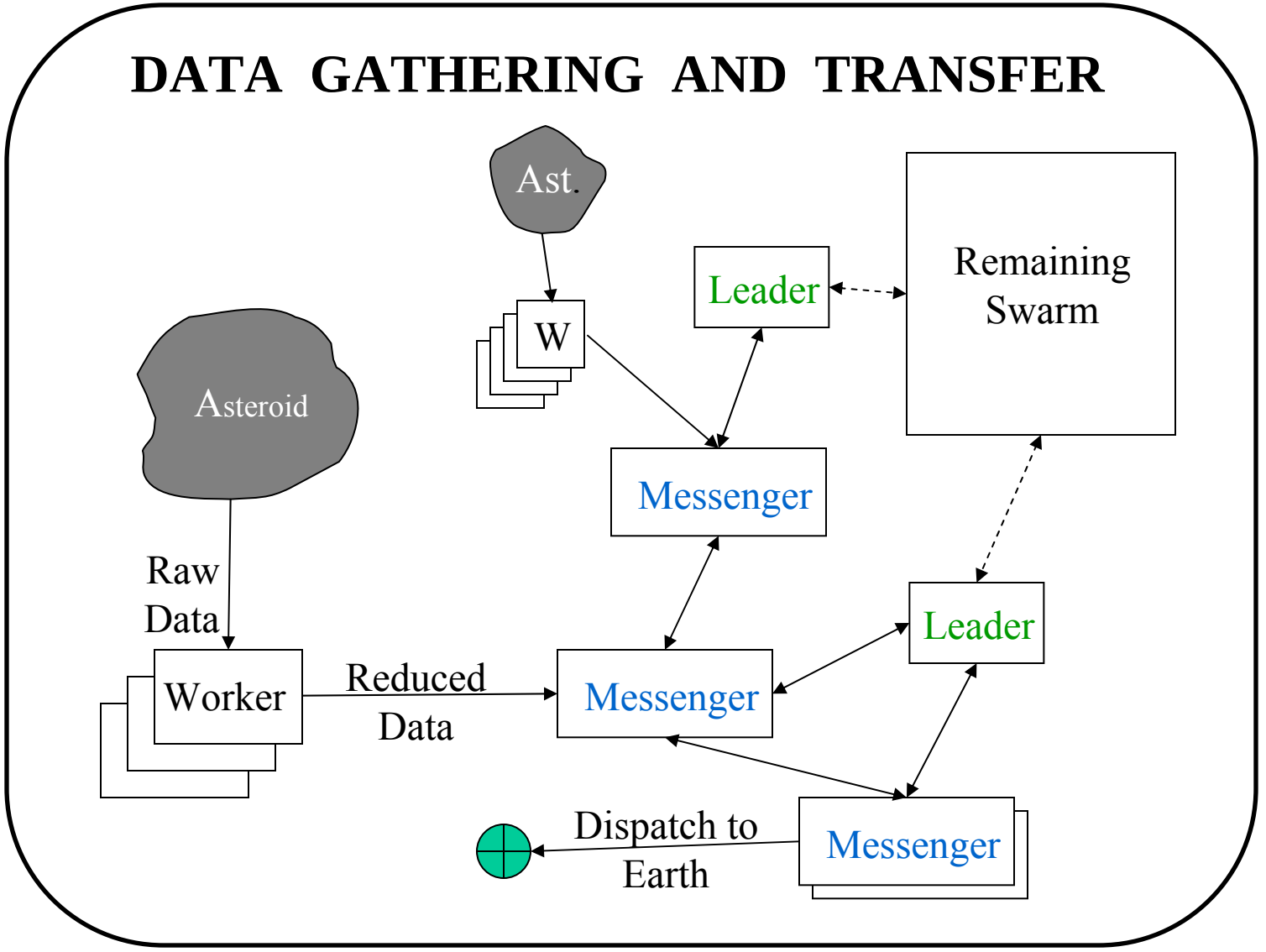
SOURCE IDENTIFICATION AND SWARM MIGRATION

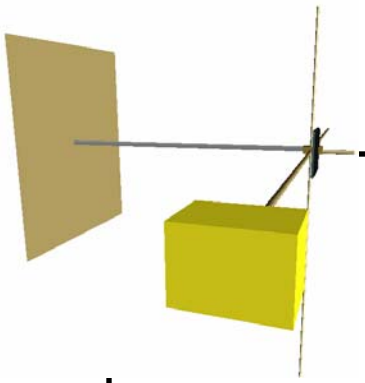


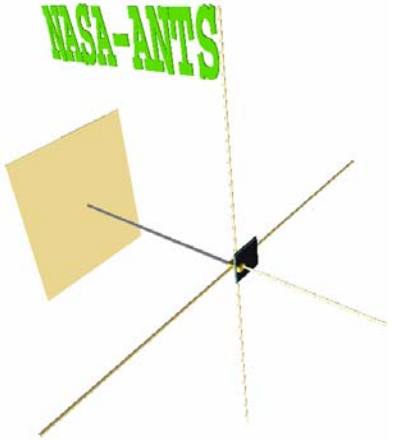
Self Directed Exploration



DATA GATHERING AND TRANSFER







CONCLUSION

- A swarm of picospacecrafts is an effective means to explore the asteroid belt.
- Technological challenges of such a mission are outlined.
- An individual ANT is a highly specialized, integrated, autonomous system.
- Mission goals are achieved through emergent, collective behavior.
- An asteroid encounter scenario illustrates the ANTS operational concept.